V. B. Fiks. *Directional Atom-Nucleus Collisions in Single Crystals—a Method of Measuring the Lifetimes of Short-Lived Nuclei and Investigating Crystals.* Methods of measuring the lifetimes of compound and excited nuclei (τ) are of great interest for nuclear spectroscopy, but it is quite difficult to find efficient "microclocks" for $\tau \lesssim 10^{-14}$ sec.

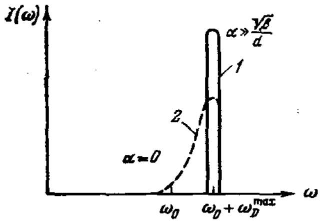
The region of existence of compound and excited nuclei with lifetimes of the order of 10^{-16}–10^{-14} sec is now least accessible to measurement, since the "shadow" method is used chiefly for times $\tau \sim 10^{-18}$–10^{16} sec and for nuclei that emit charged particles, and the method in which the Doppler shifts of γ-quanta are measured on deceleration of excited nuclei is ineffective for $\tau \lesssim 10^{-14}$ sec.

Directional atom-nucleus collisions of compound nuclei (CN) with neighboring atoms in single crystals can be used to turn the crystal into a "microclock" for measurements of $\tau \sim 10^{-16}$–10^{-14} sec, and the observed compound nuclei into indicators for study of crystals.[1-4] Let a monokinetic beam of particles (a) with a small angular divergence (~ 1–$3°$) be incident on a crystal consisting of A atoms, and let a beam B^* of CN be formed in nuclear reactions of the type $a + A \to B^* + b \to c$. By orienting the crystal relative to the nuclear beam B^*, we can aim the CN along lines of nodes, thus causing collisions of B^* nuclei with certain neighboring atoms. The following properties of directional collisions are essential:

1) By setting up nearly "head-on" collisions, it is possible with high probability to cause large-angle scattering, $\theta \geq \theta_0 \sim 1$. The probability of these collisions is $w(\theta 0) = 1 - \exp[-p^2(\theta_0)/\beta]$, where $p(\theta_0)$ is the impact parameter corresponding to the angle θ_0 and β is the mean square of the relative displacements of the B and A nuclei due to lattice-atom vibrations. The values of $w(\theta_0)$ for CN energies $\epsilon \lesssim 10^6$ eV ($\beta \approx 10^{-18}$ cm^2) lie in the range from 10^{-1} to 1.

2) The collision probability maximum lies in a narrow range of angles $\delta\alpha \lesssim (\sqrt{\beta}/d_{1s})$ (d_{1s} are the distances between nodes).

3) Collisions with different neighbors can be set up by varying the distance d_{1s}. Thus, directional collisions can be used to vary the velocity and direction of motion of the CN substantially and for stepwise adjustment of the time of flight of the nuclei between collisions. Certain parameters of the emission of compound nuclei are related to the direction of motion of the nucleus and its velocity, e.g., the energy and angular distributions of the emitted particles, etc. By analyzing the emission spectrum for an "indicator" parameter, we can determine the lifetimes of the nuclei and study the collisions.[2-3] The "indicator" parameter might be the Doppler shift ω_D of the frequency of the γ-quantum (see Figure). The angular distributions of the particles might be measured in reactions with strong anisotropy of the angular distributions. The simplest example of such anisotropy due to the kinematics of the motion is the escape of slow neutrons near the threshold of (p, n) reactions. The nucleus lifetimes that become accessible to study with the aid of directional collisions range from 10^{-16} to 10^{-14} sec, since the displacements of the nuclei between collisions $d_{1s} \sim 10^{-8}$–10^{-7} cm and their velocities $v^* = 10^7$–10^8 cm/sec. This range may include "long-lived" compound nuclei that emit particles



Form of Doppler shift of γ-quanta as a function of the angle α between the direction of the nucleus beam and the line of nodes. 1—Nondirectional collisions, $\alpha \gg \sqrt{\beta/d}$; 2—directional collisions, $\tau \approx d_{1s}/v^*$.

and ultra-short-lived "γ-excited" nuclei. For example, it would be advantageous to use this method to investigate excited nuclei in (a, γ) reactions and compound nuclei in (a, n) reactions or neutron-scattering reactions.

In reactions of the type $a + A \rightarrow B^* + b \rightarrow C^* + \gamma$, it is also possible to isolate the excited nuclei C^*, which have a definite direction of motion, and to arrange collisions between these nuclei and their neighbors. This is done by the standard method, using coincidence circuits. The direction of the primary beam and the B^* nuclei does not in this case coincide with the direction of the atomic collision. It is essential that the distribution probability of the impact parameters for the C^* nuclei depends in this collision scheme not only on β, but also on the displacement $x_\perp$ of the B^* nuclei along the normal to the line of collision, i.e., on the lifetime τ_B^* of the B^* nuclei. This dependence is in evidence at distances $x_\perp \sim \sqrt{\beta} \approx 10^{-9}$ cm and makes it possible to register values of $\tau_B^* \sim 5.10^{-18}$ sec.

Compound nuclei with known lifetimes $\tau \sim 10^{-16}-10^{-14}$ sec and all compound nuclei whose lifetimes can be determined reliably by the present method can then be used as indicator nuclei for the study of crystals. The angular coordinates of neighboring atoms relative to the indicator atom and the equilibrium positions of the indicator nuclei (atoms) in the lattice can be determined with high accuracy, of the order of 1–3°. In principle, it is possible to determine the distances to the neighboring atoms, and also the nature of these atoms, Analysis of the conditions that the indicator nuclei must satisfy indicates that there may be a considerable number of them.[4] A number of known resonant (p, γ) reactions create excited nuclei that can be used as indicators, e.g., $^{12}C(p, \gamma)^{13}N$, $^{16}O(p, \gamma)^{17}F$, $^{23}Na(p, \gamma)^{24}Mg$, $^{42}Ca(p, \gamma)^{43}Sc$.

Relatively "long-lived" nuclei with $\tau^* \lesssim 10^{-13}$ sec can be used for most problems of analysis, since the emission spectra of such nuclei are distorted only slightly by subsequent deceleration after the first collision. According to γ-spectroscopic data,[5] most nuclei with $z \lesssim 30$ have excited levels with $\tau_\gamma^* \lesssim 3 \cdot 10^{-14}$ sec.

The use of indicator nuclei may provide a helpful supplement to existing diffraction and corpuscular methods of analysis, especially in such problems as determining the positions of lattice defects, studying atomic collisions in crystals, bremsstrahlung losses, and features of radiation-induced defects.

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